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U. S. ARMY TEST AND EVALUATION COMMAND
BACKGROUND DOCUMENT

TELEMETRY

1. INTRODUCTION

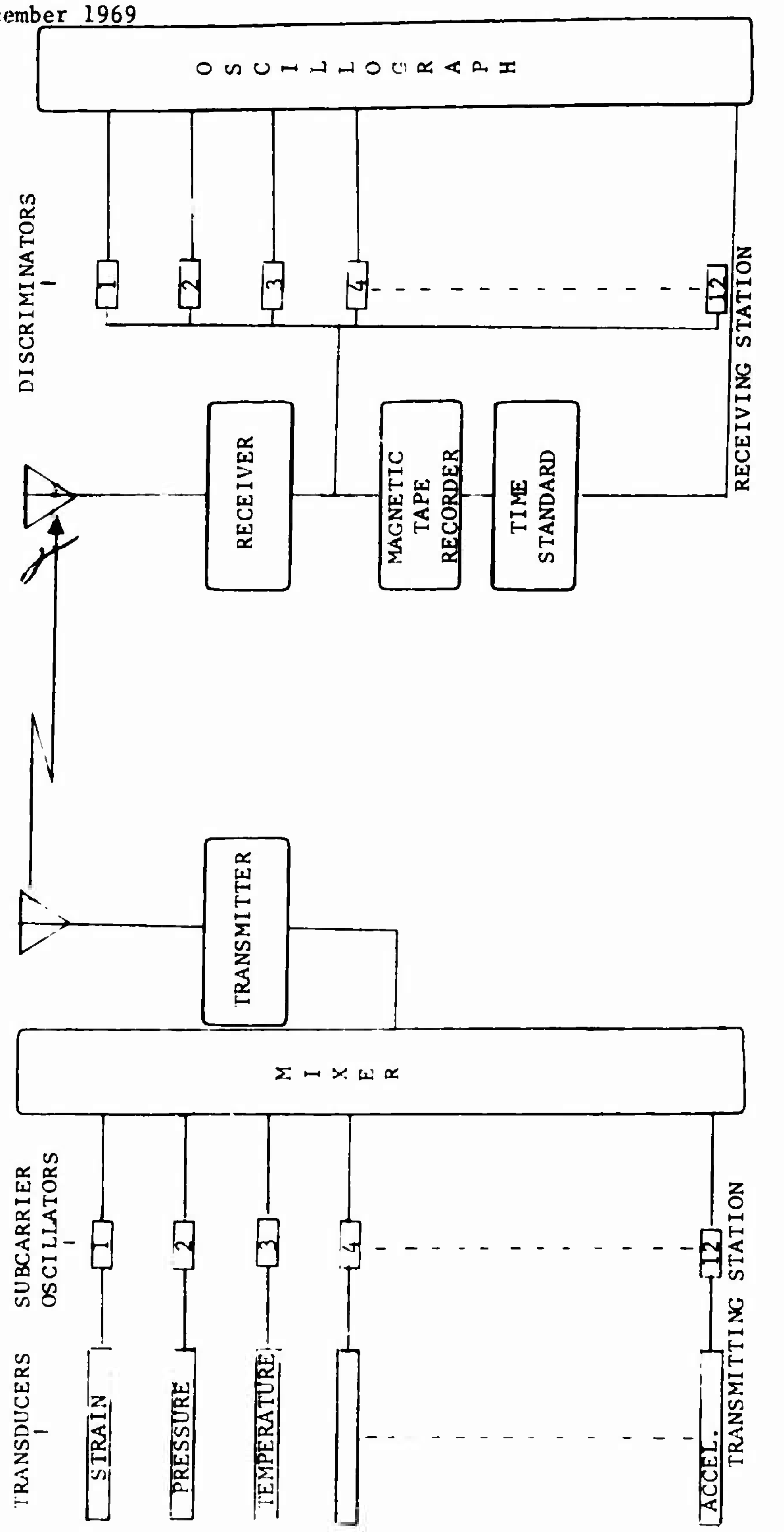
Telemetry systems (radio telemetry) provide a means for obtaining performance data from missiles and projectiles in flight or from vehicles in motion. They are used when recording instruments cannot accompany the item under test, or where hazardous conditions exist and exposure of the recording instrument or operating personnel is not advisable. Telemetry encompasses the disciplines of several fields which include instrumentation, communications, information theory and data processing. Telemetry systems are used by all military organizations to test weapons and weapon systems; by NASA in support of manned flight and satellite programs and by civilian organizations to monitor production of materials and in operational testing of their products. The discussion of telemetry systems in this MTP is directed toward those systems used with projectiles and vehicles where the data would be representative of fuze operation events; for example, switch opening or closing, time between events, operation of VT fuzes and fuze functioning; or vehicle engine temperature, fuel flow, oil pressure, velocity, engine R.P.M., torque, strain, acceleration, and displacement.

2. SYSTEMS

Telemetering is most consistently characterized as a system rather than a technique or a device. The concept includes the means of changing the variable measured into an electrical signal, the method of transmitting this signal to the receiver, and the means of changing this signal into a useful form. Figure 1 illustrates a basic Telemetry System consisting of the sensing devices (transducers), the signal conditioning devices (oscillators, multiplexers), the transmitter, receiver and signal processors (discriminators, demodulators), and recording devices.

The telemetry system provides a continuous flow of information on the performance of the operational units of the projectile or vehicle under test. The transducer monitors the changes in pressure, strain, temperature or similar physical changes. The transducer output is a voltage which has been calibrated to represent proportionately (in a voltage) the range of the parameter being monitored. The type of transducer used will of course depend on the parameter to be monitored and the range of measurement. In simple analog measurements described above, the voltage output of the transducer could vary from 0 to 5 volts. The variance will be controlled by the sensing element of the transducer. For example a strain measurement will be made with a strain gage which sensing a change in tension or compression, will vary a resistive element in the measurement circuitry and proportionately vary the voltage output of the transducer. The output of the transducer is used to control the frequency shift of a subcarrier

*Supersedes Interim Pamphlet 80-65.



BASIC TELEMETRY SYSTEM

FIGURE-1

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oscillator. The subcarrier oscillator is a very stable device which is accurately calibrated to its center, lower and upper frequencies so that it faithfully represents the control voltage from the transducer. The subcarrier oscillators feed the mixer or multiplexer where each subcarrier oscillator input is sampled periodically and its data is time shared on a common carrier frequency. An exception to this routine is when it is necessary to monitor a parameter continuously, in which case the subcarrier oscillator could be fed directly to the transmitter bypassing the mixer unit or several frequency multiplexed subcarrier oscillators could be fed to the mixer. The output of the mixer is fed to the transmitter unit composed of master oscillator, power amplifier, transmitter and antenna. The transmitter modulates all the subcarrier frequencies on a carrier frequency and radiates this signal from a surface mounted or external antenna. The receiving station picks up the transmitted signal and reverses the previous procedures so that the original transducer variations are faithfully reconstructed. The receiver removes the main carrier frequency and transfers the subcarrier frequencies (on a low frequency carrier) to the discriminators or decommutators where the subcarrier frequency is removed and a voltage representative of the original transducer voltage is recovered. This output is then recorded on an oscillograph along with a timing signal which may be external as shown in Figure 1 as part of oscillograph circuitry. The received signal need not be processed immediately but can be recorded on magnetic tape and reduced at a later time.

3. TRANSMISSION METHODS

Telemetry systems are commonly classified in accordance with the methods of multiplexing and modulation employed. The two basic methods of multiplexing are "frequency" division and "time" division. In frequency division the data signals from separate instruments are kept independent of each other by separate allocation of frequency channels, whereas in time division, separate periods of time are provided for each channel. The latter data system must be sampled on a time basis and referenced to a synchronizing signal. The latter is the method inherent in the pulse telemetry systems, whereas the former is used in the FM-FM (or FM/FM) system. The designation has the following meaning:

FM Frequency-subcarrier Modulation	FM Carrier-frequency Modulation

Similarly the following designations have the following meaning:

PCM Pulse-code modulation	FM Frequency modulation
PAM Pulse-amplitude modulation	PM Phase modulation
PDM Pulse-duration modulation	FM Frequency modulation

PWM
Pulse-width modulation

The first term applies to the subcarrier or the initial modulation (or encoding) in the telemetry transmitter. The transducers in the pulse systems must be sampled in time and the signal sample then encoded in its special time slot before the final modulation.

The PCM system encodes the sample as a binary symbol; thus it is the only commonly used binary or digital system. These four methods of subcarrier modulation represent the most standardized systems of radio telemetry.

4. TELEMETRY STANDARDS

Extensive work in standardizing the radio telemetry field has been undertaken by IRIG, the Inter-Range Instrumentation Group. This activity was started by the commanders of the Guided Missile Ranges in 1952 at their second Range Commanders' Conference. In 1957, the IRIG was expanded to include all seven existing ranges. These ranges are: (1) The Atlantic Missile Range (AMR), (2) Pacific Missile Range (PMR), (3) The White Sands Missile Range (WSMR), (4) The Naval Ordnance Test Station (China Lake, California), (5) The Naval Ordnance Missile Test Facility, (6) The Air Force Missile Development Center, and (7) The Air Proving Ground Center (Eglin Air Force Base).

The IRIG consists of a steering committee which is limited to one member from each member range. In addition there are honorary and advisory members from other government agencies and organizations. Within the IRIG there are 10 working groups representing the major areas of interest in telemetry.

There is established at White Sands Missile Range, New Mexico, a permanent IRIG secretariat to serve as a central point for steering committee correspondence and IRIG record keeping.

The working groups of the IRIG really represent the government's interest in telemetry. To represent the interest of all telemetry users and manufacturers in the matter of telemetry standards, the Telemetry Standards Coordination Committee was formed by the National Telemetry Conference in September 1960. The member societies of the NTC are:

1. American Institute of Aeronautics and Astronautics
2. Institute of Electrical and Electronic Engineers
3. Instrument Society of America

5. RADIO FREQUENCY ALLOCATION

The telemetering frequency allocations used at the various ranges are derived through government sources. The United States authority for granting frequency allocations for civilian purposes are vested in the FCC, whereas all governmental uses of the radio frequency spectrum are provided for by the IRAC (The Inter-Department Radio Advisory Committee) subject to the approval of The

Office of Civil Defense and Mobilization. It is the policy of the United States to seek international agreement concerning the allocations of frequencies that cannot be confined to national boundaries. This is negotiated through the State Department Office of Transportation and Communications. The principal agency involved is the International Telecommunications Union (ITU), Geneva, Switzerland. This union publishes radio regulations which are promulgated by the Administrative Radio Conference.

6. SUBCARRIER BANDS

The telemetry radio-frequency carrier is modulated by a group of subcarriers, each of a different frequency. The subcarriers are modulated in a manner determined by the intelligence to be transmitted. One or more of the subcarriers may be modulated by a time-division multiplex scheme (commutation) in order to increase considerably the number of individual data channels available in the system. The modulation of the radio-frequency carrier may be by either of two methods; Frequency Modulation (FM) or Phase Modulation (PM). Twenty-one standard proportionate subcarrier-band center frequencies, with accompanying information on frequency deviation and nominal intelligence frequency response, are shown in Table Ia. Twenty-one constant-bandwidth subcarrier bands are shown in Table Ib. It is intended that the standard FM/FM receiving stations at the test ranges be capable of simultaneously demodulating a minimum of any 12 of the subcarrier signals.

7. PAM/FM/FM COMMUTATION

Commutation (time-division multiplexing) may be used in one or more subcarrier bands. The specifications listed below for commutation were chosen to give maximum flexibility consistent with presently available equipment and techniques. The total number of samples per frame (number of segments of a mechanical commutator) and the frame rates may be one of the combinations shown in Table II. If a higher commutation rate is required for certain information, two or more samples per frame (equally spaced in time) can be used to represent one telemetered function at the expense of the total number of information channels. This process is referred to as cross-strapping or supercommutation.

8. PDM MODULATION

PDM systems may also be employed on the ± 15 percent deviation channels of the standard FM/FM multiplex systems. When so used, they are designated PDM/FM/FM telemetry. It should be noted that this application of PDM is wasteful of bandwidth and that it places three wide-band modulation systems in cascade. The recommended subcarrier channels for this application are bands A through E. Operating criteria for the use of these specific bands are shown in Table III.

9. TRANSMITTER AND RECEIVER FREQUENCY

The following frequency allocations have been devised for application at military test ranges where congestion of portions of the usable frequency spectrum is a severe problem. It should be noted that some space vehicles are presently using frequencies - 5000 MHz and above for telemetry transmissions.

Also, the frequencies discussed below will most probably be replaced in the future with higher frequencies to reduce the congestion of the present frequency bands.

9.1 FREQUENCY BAND 216 TO 260 MHz

9.1.1 216 To 225 MHz

Channel spacing is based on 0.5 MHz separation on the integral and one half MEGAHERTZ channels. Assignments are made on a non-interference basis to established services.

9.1.2 226 To 260 MHz

A total of 44 (500 KC) channels are allocated on a protected basis until January 1970.

9.1.3 Transmitter Systems (FM/FM; PDM/FM; PAM/FM; and PCM/FM)

9.1.4 Maximum RF Deviation - ±125 KHz (Optimum Deviation for PDM/FM Systems is ±60 to ±90 KHz)

9.2 FREQUENCY BAND 1435 TO 1535 MHz

Channel spacing of the 1435 to 1535 MHz should be in increments of 1 MHz. The 1435 to 1485 MHz portion of the band is reserved primarily for use in connection with aeronautical flight testing of manned aircraft. The 1486 of 1535 MHz portion of the band is to be reserved primarily for use in connection with aeronautical flight testing of missiles and space vehicles.

9.3 FREQUENCY BAND 2200 TO 2300 MHz

Channel spacing of the 2200 to 2300 MHz band should be in increments of 1 MHz. The 2200 to 2290 MHz portion of the band is reserved primarily for use in connection with launch vehicles, missiles, upper atmosphere research rockets, and space vehicles. The 2290 to 2300 portion is reserved primarily for use in connection with deep space telemetry exclusively.

10. SYSTEM EQUIPMENTS

10.1 GROUND STATIONS - (RECEIVING STATION)

Ground station equipments may be housed in buildings, mobile vans or even in moving vehicles. Since there are no weight or space requirements (or limitations) for this type of equipment it tends to be much larger than its airborne (or vehicle borne) counterpart. Most of the equipment is mounted in vertical racks and arranged to facilitate the normal operational and maintenance routines for this equipment. Manufacturers of telemetry equipment have standardized the size and configuration of much of the telemetry equipments so they are compatible with other telemetry equipments and with standard mountings and power sources.

Ground station equipments have advanced from the basic system shown in Figure 1 to fully automated systems where received signals are processed (to recover original data) and the data is sent directly to computer input devices for real time analysis of missile (or vehicle) performance. Pre-programmed computer routines provide a means to accomplish a complex analysis of performance, trajectory, etc. and to furnish the necessary corrections or commands to the missile (or vehicle) under test.

10.2 AIRBORNE EQUIPMENTS - (TRANSMITTING STATION)

The airborne equipments (or vehicle-borne equipment) must be designed and packaged so it will be functionally and physically correct for its intended mission, and compatible with its interfacing equipments. Since the telemetry is carried on board to measure the parameters of other equipments it should be designed so that it does not alter the performance characteristics of the projectile or vehicle with its presence. To avoid this possibility the telemetry equipment is usually designed to replace an operational equipment i.e., a warhead assembly, so its weight, size, center of gravity, etc. resembles the operational equipment. This requirement could be varied in the case of some types of vehicles where the presence of the telemetry would obviously have no effect on the operation of the vehicle, i.e. testing a tank. In addition to the requirements stated above the telemetry must be capable of withstanding all the forces and environmental conditions to which the projectile or vehicle will be exposed during the test phases. Since most of the telemetry equipments available today were developed for the military or NASA they will usually meet or exceed the needs of any test program. Much of the telemetry equipment is available "off the shelf" and with proper packaging design can support almost any mission requirement.

TABLE Ia. PROPORTIONAL SUBCARRIER BANDS

Band	Center Frequency (Hz)	Lower Limit* (Hz)	Upper Limit* (Hz)	Maximum Deviation (percent)	Frequency Response** (Hz)
1	400	370	430	±7.5	6.0
2	560	518	602		8.4
3	730	675	785		11
4	960	888	1,032		14
5	1,300	1,202	1,399		20
6	1,700	1,572	1,828		25
7	2,300	2,127	2,473		35
8	3,000	2,775	3,225		45
9	3,900	3,607	4,193		59
10	5,400	4,995	5,805		81
11	7,350	6,799	7,901		110
12	10,500	9,712	11,288		160
13	14,500	13,412	15,588		220
14	22,000	20,350	23,650		330
15	30,000	27,750	32,250		450
16	40,000	37,000	43,000		600
17	52,500	48,562	56,438		790
18	70,000	64,750	75,250		1,050
19	93,000	86,025	99,975		1,395
20	124,000	114,700	133,300		1,860
21	165,000	152,625	177,375		2,475
A***	22,000	18,700	25,300	±15	660
B	30,000	25,500	34,500		900
C	40,000	34,000	46,000		1,200
D	52,500	44,625	60,375		1,600
E	70,000	59,500	80,500		2,100
F	93,000	79,050	106,950		2,790
G	124,000	105,400	142,600		3,720
H	165,000	140,250	189,750		4,950

NOTES:

* Rounded off to nearest cycle.

** The frequency response given is based on maximum deviation and a deviation ratio of 5.

*** Bands A through H are optional and may be used by omitting adjacent numbered and lettered bands. In the process of recording the foregoing subcarriers on magnetic tape at a receiving station, provision may also be made to record a tape-speed-control tone and tape-speed-error-compensation signals.

TABLE Ib. CONSTANT BANDWIDTH SUBCARRIER BANDS

A Bands		B Bands		C Bands	
Deviation Limits = ± 2 KHz Nominal Frequency Response = 0.4 KHz		Deviation Limits = ± 4 KHz Nominal Frequency Response = 0.8 KHz		Deviation Limits = ± 8 KHz Nominal Frequency Response = 1.6 KHz	
Band	Center Frequency (KHz)	Band	Center Frequency (KHz)	Band	Center Frequency (KHz)
1A	16				
2A	24				
3A	32	3B	32		
4A	40				
5A	48	5B	48		
6A	56				
7A	64	7B	64	7C	64
8A	72				
9A	80	9B	80		
10A	88				
11A	96	11B	96	11C	96
12A	104				
13A	112	13B	112		
14A	120				
15A	128	15B	128	15C	128
16A	136				
17A	144	17B	144		
18A	152				
19A	160	19B	160	19C	160
20A	168				
21A	176	21B	176		

TABLE II. COMMUTATION SPECIFICATION FOR AUTOMATIC DECOMMUTATION

No. of Samples Per Frame*	Frame Rate (frames per sec)	Commutation rate** (samples per sec)	Lowest recommended Subcarrier Bands (Hz)
18	5	90	14,500
18	10	180	22,000 (±15%) or 30,000 (±7.5%)
18	25	450	30,000 (±15%) or 70,000 (±7.5%)
30	2.5	75	10,500
30	5	150	22,000 (±7.5%)
30	10	300	22,000 (±15%) or 40,000 (±7.5%)
30	20	600	40,000 (±15%)
30	30	900	70,000 (±15%)

NOTES:

* The number of samples per frame available to carry information is 2 less than the number indicated, because the equivalent of 2 samples is used in generating the frame-synchronizing pulse.

** Frame rate times number of samples per frame.

TABLE III. PDM OF FM/FM SUBCARRIER CHANNELS

Samples Per Second	Allocation	Channel (KHz)	Deviation Utilized (percent)	Recommended Value of Minimum Pulse Length (Microseconds)
900	B	30.0	±7.5	200 + 30 - 0
900	C	40.0	±7.5	170 + 30 - 0
900	D	52.5	±7.5	150 + 30 - 0
900	E	70.0	±7.5	110 + 30 - 0

REFERENCES

1. Cerni and Foster, Instrumentation for Engineering Measurement, Wiley, 1962.

2. Scavullo and Paul, Aerospace Ranges: Instrumentation Principles of Guided Missile Design, Van Nostrand, 1965.

3. IRIG Document 106-60*, Telemetry Standards.

4. IRIG Recommendations No. 109-59, Rev. 2, IRIG Frequency Standards for Telemetry.

5. Nichols and Rauch, Radio Telemetry, Wiley, 1956.

* IRIG Document 106-69, Telemetry Standards is in preparation. (Date of issue not known.)

GLOSSARY OF TERMS

Accuracy:	The measure of conformity to a specified value. In a transducer the ratio of the error to the full-scale output expressed as a percent of full scale output or the ratio of the error to the output, expressed as a percent.
Analog Voltage:	A voltage that varies in a continuous fashion in accordance with the magnitude of a measured variable.
Band:	A bounded continuous portion of a frequency spectrum.
Calibration:	The process of establishing a fixed, known reference base for all data.
Commutation:	Sequential sampling, on a repetitive time sharing basis, of multiple data sources for transmitting and/or recording on a single channel.
Discriminator, FM:	A device which converts variations in frequency to proportional variations in voltage or current.
Frequency Division Multiplex:	A system for the transmission of information about two or more quantities over a common channel by dividing the available frequency bands. Amplitude, frequency or phase modulation of the subcarriers may be employed.
Frequency Modulated Output:	An output which is obtained in the form of a deviation from a center frequency, where the deviation is proportional to the applied stimulus.
Frequency Shift Keying (FSK):	Modulation accomplished by switching from one discrete frequency to another discrete frequency.
Hysteresis:	The maximum difference in output, at any given measured value within the specified range, when the value is approached first with increasing and then decreasing levels. Hysteresis is expressed in percent of full scale output, during any one calibration cycle.
Subcarrier:	A carrier which is applied as a modulating wave to modulate another carrier or an intermediate deviation.
Supercommutation:	Commutation at higher rate by connection of a single data input source to equally spaced contacts of the commutator (crosspatching).

Telemetry: The science of measuring a quantity or quantities, transmitting the results to a distant station, and there interpreting, indicating and/or recording the quantities measured. Radio Telemetry involves the transmission of signals by radio communications from the source to the receiving station(s).

Transducer: A device capable of measuring stimulus and converting physical measurements to proportional voltages.

Wire Link Telemetry: Also called "hard wire" telemetry or "line" telemetry in which no radio frequency link is used.

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13. ABSTRACT

This Background Document provides general testing information relative to the operation and application of Telemetry Systems, of the types used primarily in testing of projectiles and military vehicles. This information supplements and is applied in common to test procedures which deal with evaluation of specific commodity materiel items.

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